EUROPEAN PATENT APPLICATION

㊷ Inventor: Baker, Charles Lambert, Jr.
1462 Applewood Road
Baton Rouge Louisiana 70808 (US)

Cody, George Dewey
30 Bainbridge Street
Princeton New Jersey 08540 (US)

Joseph, Craig Alan
5045 Hilier Lane
Martinez California 94553 (US)

Seia, Uri
2122 Seccombe Court
Walnut Creek California 94598 (US)

㊹ Representative: Mitchell, Alan et al
ESSO Engineering (Europe) Ltd. Patents & Licences
Apex Tower High Street
New Malden Surrey KT3 4DJ (GB)

�54 Acoustic monitoring of two-phase feed nozzles.

�57 An acoustic method is disclosed for monitoring and controlling the mixing or flow state condition of two-phase fluids through feed nozzles (4) and thereby improving operating stability and high product value yields in major refinery processes or any other process where a finely atomized liquid stream exiting the nozzle is important. In this method, the signature of a current power spectrum (CPS) from a vibrational sensor (5:8) acoustically coupled to the fluid in the nozzle (4) under unknown nozzle operating conditions are compared with the corresponding signature under known operating conditions. A difference indicating a departure from the known nozzle operating conditions is used to control the operating conditions to return the nozzle performance to normal.

FIG. I

EP 0 320 280 A2
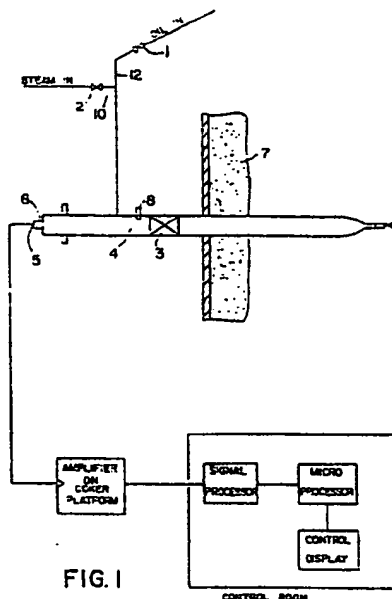
Description

ACOUSTIC MONITORING OF TWO-PHASE FEED NOZZLES

The present invention relates to an acoustic nozzle monitoring process and in particular, though not exclusively, to a process to monitor and control feed atomization in fluidized bed reactors or transfer lines. Petrochemical processes that depend on fluidized beds or transfer lines include the thermal cracking of heavy oils in processes described as "fluid bed coking" or "flexicoking", and the catalytic cracking of complex hydrocarbons in the process called "catalytic cracking" or "cat-cracking". Such processes are major components of modern refineries which use them to convert more and more difficult feedstocks into petroleum products of great added value.

One key component of either fluid bed coking or cat cracking is the feed nozzle. Feed nozzles are designed to finely atomize heavy oil in order to allow dispersion of a thin, uniform oil layer on approximately 150 micron coke particles (fluid bed coking) or approximately 60 micron catalyst particles (cat cracking). Maintaining the performance of these feed nozzles through the multi-year running cycle of a refinery is very important to operating stability and high value product yields. However, maintaining the performance of these feed nozzles can be complicated by several factors. For example the oil feed to the feed nozzles is typically very viscous and the composition of the oil is highly variable. Under these conditions, small changes in the temperature of the oil feed can have a dramatic effect on the performance of the nozzle. Furthermore, the feed nozzle is inserted in a harsh environment where erosion by particles and plugging by process deposits can both adversely affect feed nozzle performance. In addition the feed nozzles usually receive feed and steam from manifolds that supply a multiplicity of feed nozzles. Under these circumstances it is difficult, if not impossible, to ensure that each nozzle is carrying a desired flow without monitoring the specific nozzle.

Of equal importance, is the fact that the feed nozzles used in fluid bed coking and cat cracking contain a two phase mixture of non-ideal fluids namely steam and heavy oil. Because of the non-ideal nature of these mixtures, feed nozzles typically operate in a number of flow regimes. These range from the desired stable flow regime where the steam and oil are finely mixed to provide the desired atomization, up to the undesirable flow regime where steam and oil are alternately passed through the nozzle with very little mixing ("slugging").

Two of the major factors involved in obtaining a desired flow characteristic for a feed nozzle are: (1) the amount of steam injected into the feed nozzle with the heavy oil and (2) the supply pressure of the heavy oil to the feed nozzle. Steam usage in heavy oil feed nozzles performs two functions. Firstly, it keeps the feed nozzle clear from blockage when the feed oil is removed from the nozzle. Secondly, and more importantly, it disperses the heavy oil feed into fine droplets that improve the contact between the feed

oil and the coke or catalyst particles. However, since the steam introduces a highly compressible component into the oil, its presence has a major effect on the hydrodynamics of the steam/oil mixture and, therefore introduces a high degree of uncertainty into feed nozzle design. The volume of steam to volume of oil ratio used in a particular nozzle design is a key factor in obtaining a desired feed nozzle flow characteristic. This steam to oil ratio can be affected by a number of different operating conditions including feed viscosities. The supply pressure of the heavy oil feed can have a major effect on the nozzle flow characteristics as well as flow instabilities of feed nozzles supplied by a common oil manifold.

In general, obtaining and maintaining designed feed atomization is a difficult task and one that is of major importance. In fluid bed cokers, poor atomization can lead to immediate local defluidization and the formation of large agglomerates which can reduce circulation. In the extreme, so many agglomerates are formed that the entire bed may collapse. Poor feed atomization is also considered a cause of excessive build up of wall coke in cokers. Run limiting "upsets" of the process are often the result of the spalling of large chunks of coke which fall into critical regions of the circulation system and disrupt the flow. In cat crackers feed atomization has a direct effect on process yield and product composition.

Until recently, ensuring that feed nozzles are operating in the desired flow regime, and maintaining that condition under changes in feed and process conditions has been a matter of trial and error. For example nozzles could be routinely "rodded out" or mechanically cleaned. There has been no way of verifying on an operating unit, the flow regime of the nozzle since there was no direct tool to monitor flow. It has now been found, and this is the subject of this patent application, that vibrational monitoring of feed nozzles (referred to in this patent as passive acoustic nozzle monitoring) can give quantitative information on the fluid state exiting the nozzle. A well atomizing nozzle can be easily distinguished from one that is plugged, or that is exhibiting slug flow. Based on the technique of passive acoustic nozzle monitoring, operators of a fluid bed coker or cat cracker can take appropriate actions to restore the desired operating conditions. These actions could include changing the relative ratios of oil and steam, rodding or cleaning out the nozzle or isolating a "bad nozzle" from the feed distribution system.

According to the invention, there is provided an acoustic nozzle monitoring process for correcting the operating conditions of a feed nozzle injecting a liquid/gas mixture into a process vessel or chamber so as to maintain the correct mixing of said liquid and gas exiting the nozzle, comprising:

  (a) determining a Reference Power Spectrum (RPS) from a vibrational sensor acoustically

coupled to the fluid in said nozzle when said nozzle is performing at a standard mixing or flow condition which is the desired operating state of the nozzle and where the vibrational resonances that characterize the RPS are dominated by the energy associated with the flow through the nozzle in the frequency range over which the Power Spectrum is determined;

(b) determining a Current Power Spectrum (CPS) at a later time from said vibrational sensor when said nozzle is performing at an unknown mixing or flow condition;

(c) comparing the signature of said CPS with the signature of said RPS;

(d) correcting the flow state of the nozzle by changing the variables controlling the relative volumes of gas and liquid entering the nozzle, when the comparison indicates a departure of said unknown condition from said standard condition; and

(e) verifying the return to the desired flow state by recognising when the signature of the CPS substantially exhibits the signature of the RPS.

The present acoustic monitoring process can be performed as a passive acoustic process whereby the current operating state of a feed nozzle injecting a mixture of liquid and gas into a process vessel can be non-intrusively determined using the natural occurring energy in the nozzle to set up a recognizable signature of vibrational resonances which can then be compared to the vibrational signature of the desired operating state of the feed nozzle. If there is a significant difference, corrective actions, such as cleaning the nozzle or changing the relative proportions of the liquid and gas, can be undertaken. The effect of such corrective actions to restore the nozzle to its desired operating conditions will be verified by repeating the same passive acoustic process. The process is a passive acoustic process since it senses the naturally occurring vibrations that are generated by the nozzle in its performance. In many commercial situations of interest to the petrochemical industry the liquid and gas which the feed nozzle will be injecting is comprised of oil and steam. However, the method can have wider application in any situation where it is important to maintain specified flow conditions through an injecting nozzle carrying a gas-liquid mixture including particulate laden liquids such as slurries and where the reliability of the gas supply can be poor such as orifice limiting systems. It is particularly applicable to manifolded systems where the nozzles are fed by a common manifold and where the piping to the nozzle is complex due to economic constraints. Under these circumstances it is difficult, if not impossible, to achieve a specified flow through each nozzle without individual monitoring and "tuning".

In a feed nozzle where oil and steam mix and are propelled out of the nozzle by the pressure drop across the nozzle, there can exist a variety of vibratory resonances in the volumes defined by regions of restricted or turbulent flow, including the nozzle tip. These resonances are concentrations of vibrational energy in the fluid or the structure of the nozzle in certain frequency ranges and result from the excitation of the acoustic and vibratory modes of the two phase fluid nozzle system. The multiplicity of vibratory resonances of variable intensity that occur over a given frequency range with different magnitudes constitute a signature in the power spectrum of the nozzle. The power spectrum itself can be obtained in a variety of ways. For example in one embodiment of this invention, spectral analysis of the electrical output of an accelerometer in contact with the physical structure of the nozzle or of the electrical output of a dynamic pressure transducer in contact with the two phase flow within the nozzle, is utilised. From the mathematical and vibrational literature, it is conventional to display in the power spectrum the mean square acceleration per unit frequency range as a function of frequency, however any mathematical function of the mean square acceleration per unit frequency range can be utilized to obtain such a suitable power spectrum although some representations will be found to be more convenient than others.

The inventors have discovered that this power spectrum is stable in time as long as the flow state of the fluid exiting the nozzle is constant and that it can thus function as a two dimensional "signature" or "fingerprint" of the fluid state exiting the nozzle. Changes in the flow state of the nozzles brought about by changes in the nozzle tip or bore ("plugging") or by changes in the fluid inputs ("slugging") can be detected and corrected by appropriate procedures to return the power spectrum to that corresponding to the desired flow state. Furthermore, the power spectrum can be used to confirm that the corrective action has produced a return to the desired flow state. Recognition of significant changes in the power spectrum can be accomplished by a human observer in the case of periodic nozzle monitoring or by suitable pattern recognition algorithms in the case of continuous or real time nozzle monitoring. Furthermore, the power spectrum can be obtained simply and non-intrusively while the nozzle is operating. Examples of the correlation between the power spectrum of a particular nozzle and different flow conditions from that nozzle will be discussed below. The frequency range of the power spectrum is chosen so that resonances generated by the energy of the operating noise of the nozzle dominate the power spectrum.

It is surprising indeed that it is possible to find a frequency range where meaningful information can be obtained about nozzle flow conditions that is not masked by the background noise level of the reactor.

Under certain flow conditions additional information can be obtained from the time variation of the vibratory signal. For example, the fluid exiting the nozzle can be regularly alternating its flow state(e.g. intermittent slugging or sputtering or just unsteady flow). This is an undesired state of flow and as such will exhibit itself in changes in the power spectrum. The power spectrum is the fourier transform of the time variation of vibrating signal. However, it will also be a recognizable feature of the time variation of the

vibrational signal and this time signature can be used to complement the information contained in the power spectrum. Again, examples of the correlation between certain time signatures and the flow states of the fluid exiting the nozzle will be given below.

A preferred way of performing the passive acoustic nozzle monitoring process includes the following steps:

1. A reference power spectrum (Reference Power Spectrum of RPS) is obtained from a vibrational sensor in close proximity to the nozzle or the fluid contained within when the nozzle is atomizing feed in the desired manner. This Reference Power Spectrum (RSP) is specific to a nozzle of specified mechanical dimensions and fluid connections and has to be determined empirically because of the well-known complexity of two phase flow. Clearly under steady state conditions the RPS will not change. The vibrational sensor is either an accelerometer attached to the nozzle shell or a pressure transducer in contact with the fluid within the nozzle. The frequency range over which the power spectrum is plotted is chosen empirically so that the vibrational resonances that characterize the power spectrum are dominated by energy produced by nozzle flow.

2. Subsequent current power spectra (Current Power Spectrum or CPS) are taken in either real time by a hard wired system monitored by a computer or taken periodically by operating personnel at the specific nozzle.

3. Comparison of the RPS with the CPS is made either by suitable computer pattern recognition algorithms or visually by personnel and changes noted.

4. Changes in the operating conditions of a specific nozzle are then made to restore the CPS to the RPS.

5. The time variation of the vibratory signal that accompanies the taking of both the RPS and the CPS can be noted and used either by a suitable computer algorithm or by observation of personnel to supply complementary information on the time variation of the state of fluid flow within the nozzle within the measurement time.

The invention will be better understood from the following description given by way of example and with reference to the accompanying drawings, wherein:-

Figure 1 shows a schematic diagram of one form of nozzle performance monitoring system according to the present invention.

Figure 2 shows a schematic figure of two nozzles being fed oil and steam through common headers.

Figure 3 shows the relationship between signal measured from the accelerometer and the power spectrum.

Figure 4 shows the variation of the power spectrum as the flow conditions of a nozzle vary. The ordinate is in (volts)^2 Hz. The abscissa is in Hz. All pressures, P, are in PSI.

Figure 5 is another example of the variation of

the power spectrum as the flow conditions of the nozzle vary. The ordinate is in (volts)^2/Hz. The abscissa is in Hz. All pressures, P, are in PSI.

Figure 6 shows the spectra of a nozzle obtained with a pressure transducer for a variety of flow conditions. The ordinate is the log of RMS pressure. The abscissa is in Hz from 0 to 32000 Hz.

Figure 7 shows the time variation of the vibrating signal and the corresponding power spectrum for the same nozzle conditions.

Figure 8 shows the time variation of the vibrating signal for normal oil flow and unstable oil flow.

Disclosed hereinbelow is a method for non-intrusively determining if the liquid-gas mixture exiting a nozzle has departed from desired operating conditions. If it has, then the operating conditions of the nozzle are changed to return to the desired flow conditions, or the nozzle is cleaned, or removed from service. The method will be illustrated and described by a heavy feed fluid bed thermal conversion process such as in a fluid bed coker where the nozzle contains feed oil and steam. However, it is not limited to petrochemical applications but to any situation where nozzle performance is to be monitored, and in particular where it is difficult to directly monitor flow through a specific nozzle and where the fluid being carried, or the nozzle environment, leads to a high probability of unreliable nozzle performance.

Figure 1 shows a schematic diagram of a representative coker feed nozzle 4 inserted through a coker wall 7. Fluid bed cokers can contain anywhere from twenty to sixty such nozzles injecting feed at the rate of approximately ten to fifty gallons a minute. In one embodiment of the invention, an accelerometer 5 is placed in close proximity to the nozzle 4. In Figure 1, the accelerometer 5 is placed on the rodding plug 6, but any location in proximity to the nozzle and where the accelerometer is sensitive to changes in flow conditions is acceptable.

As shown in Figure 2, for a given reactor, several nozzles 4 and 11 may be interconnected so that steam and oil are supplied through a steam header 14 and oil header 16 to all nozzles simultaneously. In this case, the performance of one nozzle (upstream) can affect the power spectra observed for another (discussed below).

The electrical signal for the accelerometer is proportional to the nozzles vibration intensity and a plot of the mean square acceleration per unit frequency range or simple mathematical operations on this quantity (e.g. taking the square root of this quantity and multiplying by a constant to form a plot of the root mean square acceleration or taking the logarithm of the quantity to form a "db" plot) is an appropriate power spectrum for the purpose of the present disclosure. In one use the sensor signal is amplified and transmitted by an appropriate data link to a control room as shown in Figure 1. In the control room, the signal is processed by a spectrum analyzer or fast fourier transform signal processor. Also in the control room by an appropriate algorithm,

the RPS is displayed and stored in memory. Similarly current power spectra or CPS are taken in real time and by a suitable pattern recognition algorithm compared to the RPS. Changes between the CPS and the RPS are brought to the attention of the operator to indicate changes in the flow regime of a specific nozzle for subsequent correction.

To assist the operator in interpreting the changes in the CPS from the RPS, a "dictionary" of characteristic CPS associated with specific flow conditions can be contained in memory and displayed to indicate the direction of changes to be made. Again the "dictionary" is feed nozzle specific and has been generated empirically due to the well known complexity of two phase flow in complex piping. The determination of a dictionary is illustrated and described below.

In addition an analysis of the time variation of the real time signal from the accelerometer sensor (time signature) is used to detect the presence of unstable flow during the measurement time.

Alternatively, the vibratory signal from the accelerometer can be processed at the nozzle by a portable spectrum analyzer operated by a technician and changes in the CPS from the RPS noted and corrective action taken with respect to a nozzle can be taken immediately at the nozzle location.

In another embodiment, the accelerometer 5 is replaced by a dynamic pressure transducer 8 in contact with the fluid. In this case, the transducer penetrates the rodding plug to contact the fluid. Alternately, the transducer 8 may be located elsewhere along the nozzle (see Fig. 1). The frequency dependent pressure can be used to generate a power spectrum to serve as an RPS or a CPS.

Figure 3 exhibits the relationship between the time varying electrical signal produced either by an accelerometer in contact with the mechanical shell of a feed nozzle or a pressure transducer in contact with the two phase mixture within the nozzle and the frequency distribution of the vibrational energy generated by the nozzle in its operation. It also shows the square of that signal as a function of time and frequency and exhibits the well known relationship between the area under the power spectrum and the mean square signal (mean square acceleration or mean square pressure fluctuation when the transducers are correctly calibrated) produced by the vibrational sensor.

Determining Of Dictionary For a Nozzle

A dictionary for a given nozzle is obtained by doing a power spectrum analysis for different flow conditions. Figure 4 shows a sequence of power spectra of a nozzle for changes in flow conditions as induced by oil flow changes by valve (1) in Fig. 1 or steam flow changes by valve 2 in Fig. 1, or conditions of nozzles upstream on the same oil and steam headers.

Figure 4(a) shows a power spectrum for a nozzle where the oil and steam are set at normal pressure of 175 but which exhibits unstable and undesirable flow. The pressure is measured at point 10 in Figure 1. The nozzle is then rodded and cleaned. Figures 4(b), 4(c), 4(d) and 4(e) show a power spectra of the

nozzle as oil flow is reduced with some steam input until the oil flow is shut off. The pressures, P, are 150, 130, 100 and 20, respectively. There is no chugging. Figure 4 (f) shows the power spectrum for the nozzle after normal oil and steam flow are resumed. Pressure is 175 and there is no chugging. Figure 4(g) shows the power spectrum for the nozzle with the steam shut off and only oil flow. Pressure is 300. Figure 4(h) shows the power spectrum of the nozzle after normal oil and steam flow are resumed. The pressure is 175 and there is no chugging.

Nozzle malfunctions resulting from an inadequate mixing of feed and steam may be correlated to the various open and closed valves as presented and discussed in Figure 4. These include: partial or complete blockage of the nozzle due to deposits, oil off, steam off, improper proportions of steam to oil, fluctuating flow or chugging, as well as poor atomization, time dependent shifts in flow between two nozzles on the same feed ring as well as physically damaged nozzles. Figures 5 is another example of power spectra generated by an accelerometer in contact with the shell of the nozzle corresponding to such states. Figure 5 shows acceleration power spectra taken for a different feed nozzle under different flow conditions. Pressure is measured at point 10 in Figure 1.

Figure 5(a) shows the power spectrum for the nozzle while it is plugged (no flow). Figure 5(b) shows the power spectrum of the nozzle when it is chugging showing unstable flow. The pressure is 183. Figure 5(c) shows the power spectrum of the nozzle after is has been cleared showing stable flow. The pressure is again 183. Figure 5(d) shows the power spectrum of the nozzle with only oil flow (steam off). Pressure is 300. Figure 5(e) shows the power spectrum of the nozzle with only steam flow (oil off). Pressure is 50. Figure 5(f) shows the power spectrum of the nozzle when another nozzle upstream on the same oil and steam headers is plugged. In this case, pressure is measured at point 12 in Figure 1. It is important to note that despite differences between the power spectra of Figure 4 and 5, each is a "fingerprint" of flow states.

An accelerometer will often be the vibrational transducer of choice for generation of the RPS and CPS. However a pressure transducer is an alternative that exhibits some advantages. It is often possible to place the pressure transducer at a location where it can not be inadvertently damaged when cleaning a nozzle. There is no difference in the frequency coverage between an accelerometer and a pressure transducer for the vibratory signals of interest to passive acoustic feed nozzle monitoring. Furthermore, the efficiency of a pressure transducer in contact with the fluid is little affected by a build up of coke or other solids on its active surface since it is acoustic rather that mechanical contact that is important.

As discussed above, a dynamic pressure transducer (8) in contact with the fluid within the feed nozzle at a fixed location on the feed nozzle may be used to obtain a power spectrum. The power spectrum from such a transducer is shown in Fig. 6(a) through 6(f) show the power spectra of a

nozzle when it is operating correctly (6a), steam only (6b), same steam, reduced oil (6c), oil, no steam (6d) induced slugging by adding steam (6e) and nozzle instability induced by plugging up-stream nozzle (6f). A log scale is used for these figures to give greater dynamic range.

From the above figures, it is clear that the pressure transducer produces an equally distinct power spectrum to function as a CPS or RPS as does the accelerometer generated power spectrum. However the pressure transducer generated power spectrum is simpler in that it contains a smaller number of peaks and hence more changes in it are more readily recognized by either a human observer in the case of periodic nozzle monitoring or by simpler computer pattern recognition algorithm in the case of continuous or real time nozzle monitoring.

The simplicity of the pressure transducer generated power spectrum can be understood if we note that the peaks in the power spectrum arise from resonances in the fluid contained in the bore or ancillary tubing of the feed nozzle which have been excited by broadband noise from the fluid exiting the nozzle tip. The peaks in the power spectrum generated by the accelerometer in contact with the nozzle shell contain as well vibrational resonances associated with the mechanical vibrational modes of the nozzle as well as structural modes of the process vessel. Using the concept of acoustic impedance, it is easily shown that the signals produced by resonances in the fluid are favored over other resonances when measured in the fluid by a factor of almost 100. Apart from this fact, another advantage for the pressure transducer generated CPS is that it may often be advantageous to use a pressure transducer for convenience of location and protection from unintended damage during nozzle maintenance.

As discussed above, the time variation of the vibrational signal also may be used to obtain information regarding the state of the flow of fluid in the nozzle. Figure 7(b) shows the time variation of the vibrating signal and the corresponding Fourier transform in Figure 7(a), the power spectrum as a function of frequency for a chugging nozzle. It is sometimes more convenient to use the time variation of the probe signal to detect unstable flow. Fig. 8 compares the time variation for stable oil flow (a) and unstable oil flow, chugging (b).

Claims

1. An acoustic nozzle monitoring process for correcting the operating conditions of a feed nozzle (4) injecting a liquid/gas mixture into a process vessel or chamber so as to maintain the correct mixing of said liquid and gas exiting the nozzle, comprising:

(a) determining a Reference Power Spectrum (RPS) from a vibrational sensor acoustically coupled to the fluid in said nozzle when said nozzle (4) is performing at a standard mixing or flow condition which is the desired operating state of the nozzle and where the vibrational resonances that characterize the RPS are dominated by the energy associated with the flow through the nozzle in the frequency range over which the Power Spectrum is determined;

(b) determining a Current Power Spectrum (CPS) at a later time from said vibrational sensor when said nozzle is performing at an unknown mixing or flow condition;
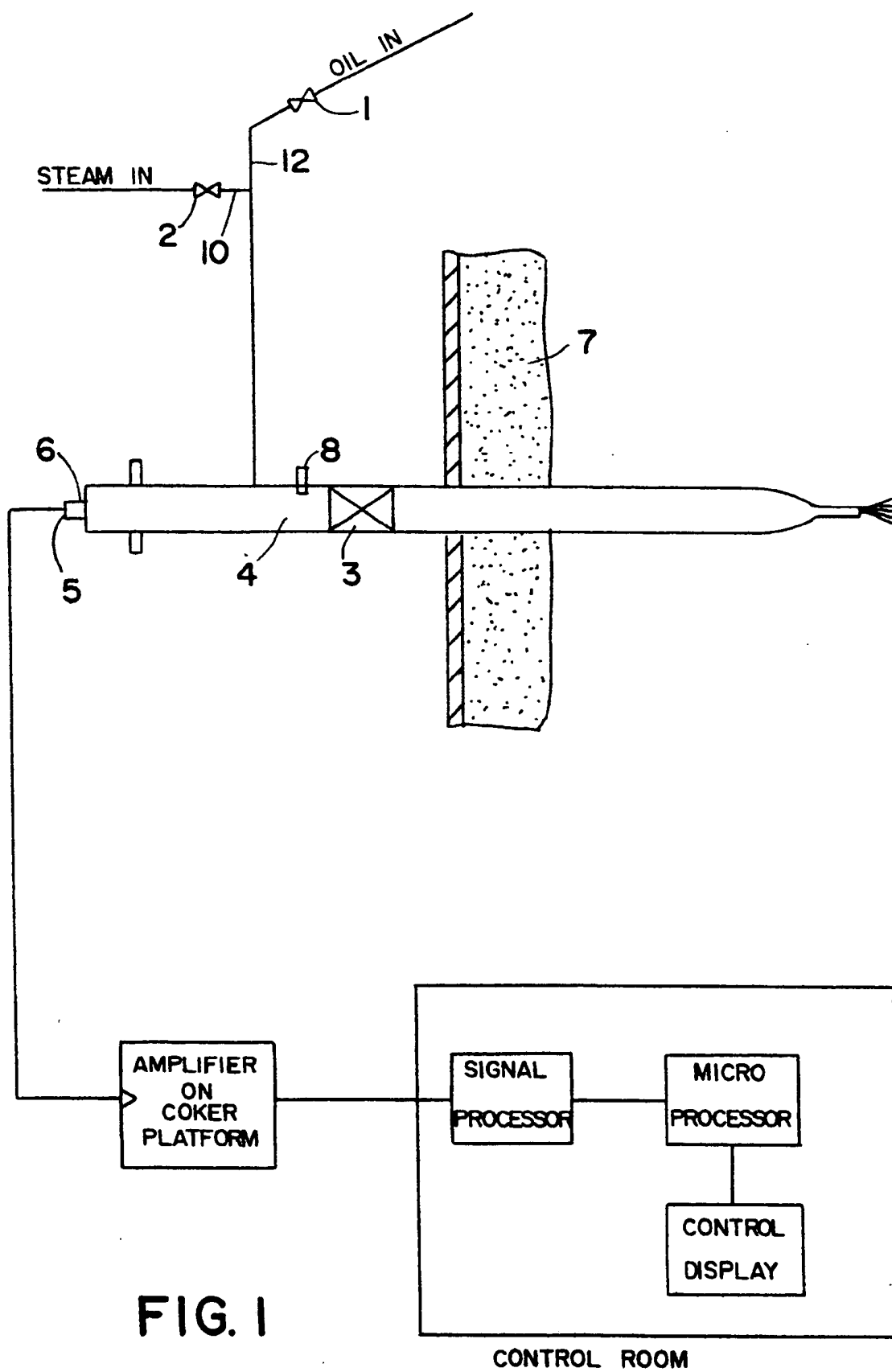
(c) comparing the signature of said CPS with the signature of said RPS;

(d) correcting the flow state of the nozzle by changing the variables controlling the relative volumes of gas and liquid entering the nozzle, when the comparison indicates a departure of said unknown condition from said standard condition; and

(e) verifying the return to the desired flow state by recognising when the signature of the CPS substantially exhibits the signature of the RPS.

2. A process as claimed in claim 1, wherein said vibrational sensor is an accelerometer (5).

3. A process as claimed in claim 1, wherein said vibrational sensor is a dynamic pressure transducer (8) in contact with the fluid mixture in the nozzle.
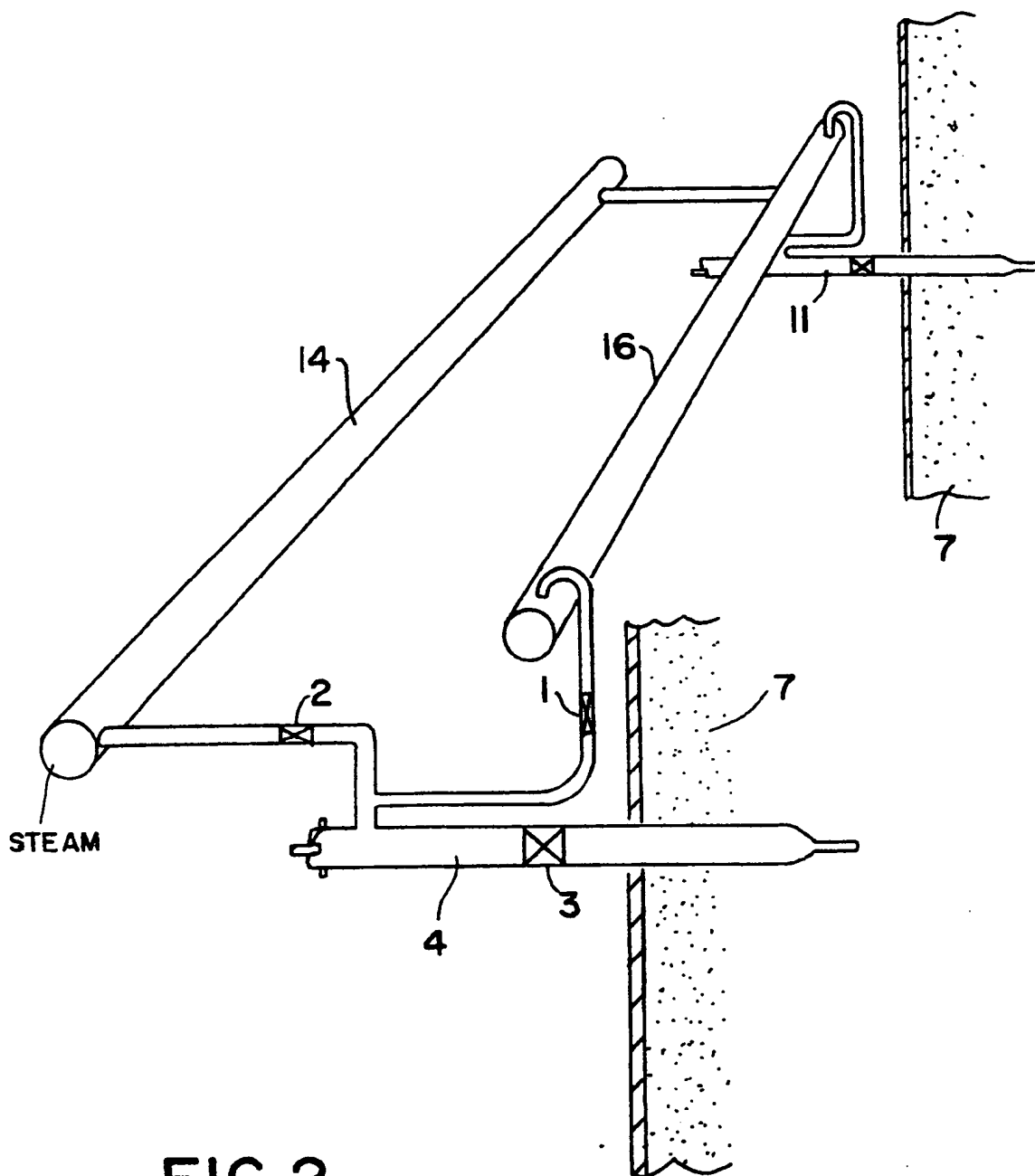
OIL IN

1

12

STEAM IN

2

10

7

6

8

5

4

3

AMPLIFIER
ON
COKER
PLATFORM

SIGNAL

PROCESSOR

MICRO

PROCESSOR

CONTROL

DISPLAY

FIG. I

CONTROL ROOM

14

16

11

7

2

1

7

STEAM

4

3

FIG. 2

POWER SPECTRUM EXHIBITS FREQUENCY DEPENDENCE OF RANDOM TIME SIGNAL

FROM ACCELEROMETER (PRESSURE)

$A(T)$

T = TIME

MEAN ACCELERATION (PRESSURE)
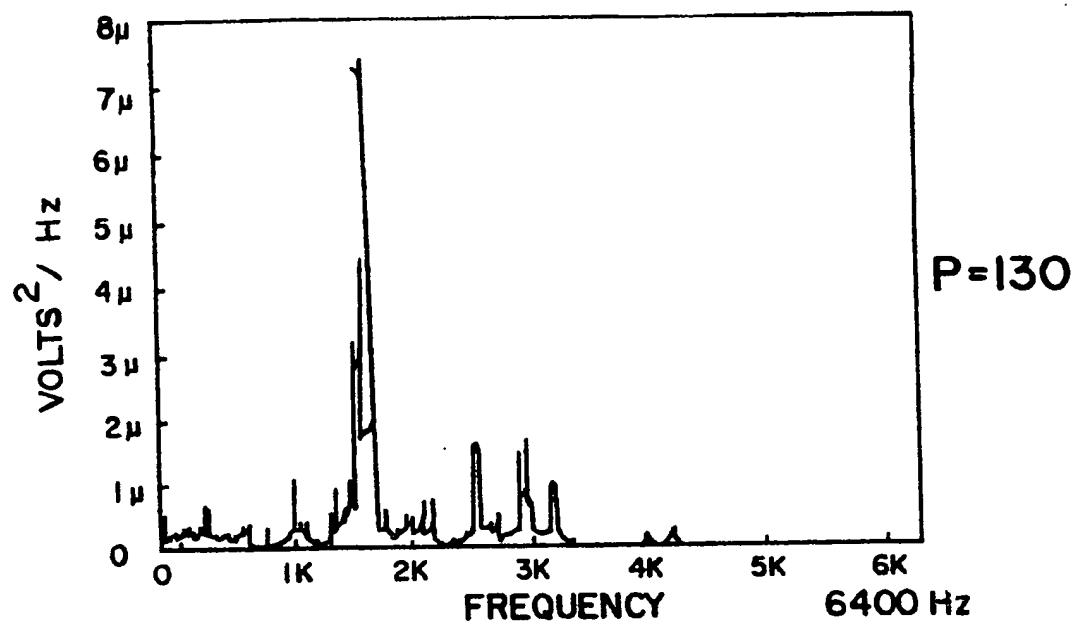
$\langle A(T) \rangle = 0$

$A^2(T)$

$\langle A^2(T) \rangle$

MEAN SQUARE ACCELERATION
(PRESSURE)

$\langle A^2(T) \rangle = 2 \int S(F) \, dF$

POWER SPECTRUMS(F)

FREQUENCY F (Hz)

S = POWER SPECTRUM = $\dfrac{POWER}{Hz}$

FIG.3

FIG.4a

FIG.4b

FIG.4c

P=130

FIG.4d

P=100

FIG.4e

FIG.4f

FIG.4g

FIG.4h

FIG.5a

FIG.5b

FIG.5c

FIG.5d

FIG. 5 e

FIG. 5 f

FIG. 6 a

FIG. 6 b

FIG. 6c

(Figures 6a, 6b, 6c: graphs of LOG RMS PRESSURE versus FREQUENCY, F, ranging to 3200 Hz)

FIG. 6 d

LOG RMS PRESSURE

FREQUENCY, F   3200 Hz

FIG. 6 e

LOG RMS PRESSURE

FREQUENCY, F   3200 Hz

FIG. 6 f

LOG RMS PRESSURE

FREQUENCY, F   3200 Hz

FIG.7a

FIG.7b

FIG.8a

FIG.8b

EUROPEAN PATENT SPECIFICATION

(54) **Acoustic monitoring of two-phase feed nozzles.**

(73) Proprietor: **EXXON RESEARCH AND ENGI-
NEERING COMPANY**
P.O.Box 390, 180 Park Avenue
Florham Park, New Jersey 07932(US)

(72) Inventor: **Baker, Charles Lambert, Jr.**
1462 Applewood Road
Baton Rouge Louisiana 70808(US)
Inventor: **Cody, George Dewey**
30 Bainbridge Street
Princeton New Jersey 08540(US)
Inventor: **Joseph, Craig Alan**
5045 Hiller Lane
Martinez California 94553(US)
Inventor: **Sela, Uri**
2122 Seccombe Court
Walnut Creek California 94598(US)

(74) Representative: **Mitchell, Alan et al**
**ESSO Engineering (Europe) Ltd. Patents &
Licences Mailpoint 72 Esso House Ermyn
Way**
Leatherhead, Surrey KT22 8XE (GB)

EP 0 320 280 B1

Description

The present invention relates to an acoustic nozzle monitoring process and in particular, though not exclusively, to a process to monitor and control feed atomization in fluidized bed reactors or transfer lines. Petrochemical processes that depend on fluidized beds or transfer lines include the thermal cracking of heavy oils in processes described as "fluid bed coking" or "flexicoking", and the catalytic cracking of complex hydrocarbons in the process called "catalytic cracking" or "cat-cracking". Such processes are major components of modern refineries which use them to convert more and more difficult feedstocks into petroleum products of great added value.

One key component of either fluid bed coking or cat cracking is the feed nozzle. Feed nozzles are designed to finely atomize heavy oil in order to allow dispersion of a thin, uniform oil layer on approximately 150 micron coke particles (fluid bed coking) or approximately 60 micron catalyst particles (cat cracking). Maintaining the performance of these feed nozzles through the multi-year running cycle of a refinery is very important to operating stability and high value product yields. However, maintaining the performance of these feed nozzles can be complicated by several factors. For example the oil feed to the feed nozzles is typically very viscous and the composition of the oil is highly variable. Under these conditions, small changes in the temperature of the oil feed can have a dramatic effect on the performance of the nozzle. Furthermore, the feed nozzle is inserted in a harsh environment where erosion by particles and plugging by process deposits can both adversely affect feed nozzle performance. In addition the feed nozzles usually receive feed and steam from manifolds that supply a multiplicity of feed nozzles. Under these circumstances it is difficult, if not impossible, to ensure that each nozzle is carrying a desired flow without monitoring the specific nozzle.

Of equal importance, is the fact that the feed nozzles used in fluid bed coking and cat cracking contain a two phase mixture of non-ideal fluids namely steam and heavy oil. Because of the non-ideal nature of these mixtures, feed nozzles typically operate in a number of flow regimes. These range from the desired stable flow regime where the steam and oil are finely mixed to provide the desired atomization, up to the undesirable flow regime where steam and oil are alternately passed through the nozzle with very little mixing ("slugging").

Two of the major factors involved in obtaining a desired flow characteristic for a feed nozzle are: (1) the amount of steam injected into the feed nozzle

with the heavy oil and (2) the supply pressure of the heavy oil to the feed nozzle. Steam usage in heavy oil feed nozzles performs two functions. Firstly, it keeps the feed nozzle clear from blockage when the feed oil is removed from the nozzle. Secondly, and more importantly, it disperses the heavy oil feed into fine droplets that improve the contact between the feed oil and the coke or catalyst particles. However, since the steam introduces a highly compressible component into the oil, its presence has a major effect on the hydrodynamics of the steam/oil mixture and, therefore introduces a high degree of uncertainty into feed nozzle design. The volume of steam to volume of oil ratio used in a particular nozzle design is a key factor in obtaining a desired feed nozzle flow characteristic. This steam to oil ratio can be affected by a number of different operating conditions including feed viscosities. The supply pressure of the heavy oil feed can have a major effect on the nozzle flow characteristics as well as flow instabilities of feed nozzles supplied by a common oil manifold.

In general, obtaining and maintaining designed feed atomization is a difficult task and one that is of major importance. In fluid bed cokers, poor atomization can lead to immediate local defluidization and the formation of large agglomerates which can reduce circulation. In the extreme, so many agglomerates are formed that the entire bed may collapse. Poor feed atomization is also considered a cause of excessive build up of wall coke in cokers. Run limiting "upsets" of the process are often the result of the spalling of large chunks of coke which fall into critical regions of the circulation system and disrupt the flow. In cat crackers feed atomization has a direct effect on process yield and product composition.

Until recently, ensuring that feed nozzles are operating in the desired flow regime, and maintaining that condition under changes in feed and process conditions has been a matter of trial and error. For example nozzles could be routinely "rodded out" or mechanically cleaned. There has been no way of verifying on an operating unit, the flow regime of the nozzle since there was no direct tool to monitor flow. It has now been found, and this is the subject of this patent application, that vibrational monitoring of feed nozzles (referred to in this patent as passive acoustic nozzle monitoring) can give quantitative information on the fluid state exiting the nozzle. A well atomizing nozzle can be easily distinguished from one that is plugged, or that is exhibiting slug flow. Based on the technique of passive acoustic nozzle monitoring, operators of a fluid bed coker or cat cracker can take appropriate actions to restore the desired operating conditions. These actions could include changing the relative ratios of oil and steam, rodding or cleaning

out the nozzle or isolating a "bad nozzle" from the feed distribution system.

According to the invention, there is provided an acoustic nozzle monitoring process for correcting the operating conditions of a feed nozzle injecting a liquid/gas mixture into a process vessel or chamber so as to maintain the correct mixing of said liquid and gas exiting the nozzle, comprising:

(a) determining a Reference Power Spectrum (RPS) from a vibrational sensor acoustically coupled to the fluid in said nozzle when said nozzle is performing at a standard mixing or flow condition which is the desired operating state of the nozzle and where the vibrational resonances that characterize the RPS are dominated by the energy associated with the flow through the nozzle in the frequency range over which the Power Spectrum is determined;

(b) determining a Current Power Spectrum (CPS) at a later time from said vibrational sensor when said nozzle is performing at an unknown mixing or flow condition;

(c) comparing the signature of said CPS with the signature of said RPS;

(d) correcting the flow state of the nozzle by changing the variables controlling the relative volumes of gas and liquid entering the nozzle, when the comparison indicates a departure of said unknown condition from said standard condition; and

(e) verifying the return to the desired flow state by recognising when the signature of the CPS substantially exhibits the signature of the RPS.

The present acoustic monitoring process can be performed as a passive acoustic process whereby the current operating state of a feed nozzle injecting a mixture of liquid and gas into a process vessel can be non-intrusively determined using the natural occurring energy in the nozzle to set up a recognizable signature of vibrational resonances which can then be compared to the vibrational signature of the desired operating state of the feed nozzle. If there is a significant difference, corrective actions, such as cleaning the nozzle or changing the relative proportions of the liquid and gas, can be undertaken. The effect of such corrective actions to restore the nozzle to its desired operating conditions will be verified by repeating the same passive acoustic process. The process is a passive acoustic process since it senses the naturally occurring vibrations that are generated by the nozzle in its performance. In many commercial situations of interest to the petrochemical industry the liquid and gas which the feed nozzle will be injecting is comprised of oil and steam. However, the method can have wider application in any situation where it is important to maintain specified flow conditions through an injecting nozzle carrying a gas-liquid

mixture including particulate laden liquids such as slurries and where the reliability of the gas supply can be poor such as orifice limiting systems. It is particularly applicable to manifolded systems where the nozzles are fed by a common manifold and where the piping to the nozzle is complex due to economic constraints. Under these circumstances it is difficult, if not impossible, to achieve a specified flow through each nozzle without individual monitoring and "tuning".

In a feed nozzle where oil and steam mix and are propelled out of the nozzle by the pressure drop across the nozzle, there can exist a variety of vibratory resonances in the volumes defined by regions of restricted or turbulent flow, including the nozzle tip. These resonances are concentrations of vibrational energy in the fluid or the structure of the nozzle in certain frequency ranges and result from the excitation of the acoustic and vibratory modes of the two phase fluid nozzle system. The multiplicity of vibratory resonances of variable intensity that occur over a given frequency range with different magnitudes constitute a signature in the power spectrum of the nozzle. The power spectrum itself can be obtained in a variety of ways. For example in one embodiment of this invention, spectral analysis of the electrical output of an accelerometer in contact with the physical structure of the nozzle or of the electrical output of a dynamic pressure transducer in contact with the two phase flow within the nozzle, is utilised. From the mathematical and vibrational literature, it is conventional to display in the power spectrum the mean square acceleration per unit frequency range as a function of frequency, however any mathematical function of the mean square acceleration per unit frequency range can be utilized to obtain such a suitable power spectrum although some representations will be found to be more convenient than others.

The inventors have discovered that this power spectrum is stable in time as long as the flow state of the fluid exiting the nozzle is constant and that it can thus function as a two dimensional "signature" or "fingerprint" of the fluid state exiting the nozzle. Changes in the flow state of the nozzles brought about by changes in the nozzle tip or bore ("plugging") or by changes in the fluid inputs ("slugging") can be detected and corrected by appropriate procedures to return the power spectrum to that corresponding to the desired flow state. Furthermore, the power spectrum can be used to confirm that the corrective action has produced a return to the desired flow state. Recognition of significant changes in the power spectrum can be accomplished by a human observer in the case of periodic nozzle monitoring or by suitable pattern recognition algorithms in the case of continuous or real time nozzle monitoring. Further-

more, the power spectrum can be obtained simply and non-intrusively while the nozzle is operating. Examples of the correlation between the power spectrum of a particular nozzle and different flow conditions from that nozzle will be discussed below. The frequency range of the power spectrum is chosen so that resonances generated by the energy of the operating noise of the nozzle dominate the power spectrum.

It is surprising indeed that it is possible to find a frequency range where meaningful information can be obtained about nozzle flow conditions that is not masked by the background noise level of the reactor.

Under certain flow conditions additional information can be obtained from the time variation of the vibratory signal. For example,the fluid exiting the nozzle can be regularly alternating its flow state (e.g. intermittent slugging or sputtering or just unsteady flow). This is an undesired state of flow and as such will exhibit itself in changes in the power spectrum. The power spectrum is the fourier transform of the time variation of vibrating signal. However, it will also be a recognizable feature of the time variation of the vibrational signal and this time signature can be used to complement the information contained in the power spectrum. Again, examples of the correlation between certain time signatures and the flow states of the fluid exiting the nozzle will be given below.

A preferred way of performing the passive acoustic nozzle monitoring process includes the following steps:

1. A reference power spectrum (Reference Power Spectrum or RPS) is obtained from a vibrational sensor in close proximity to the nozzle or the fluid contained within when the nozzle is atomizing feed in the desired manner. This Reference Power Spectrum (RSP) is specific to a nozzle of specified mechanical dimensions and fluid connections and has to be determined empirically because of the well-known complexity of two phase flow. Clearly under steady state conditions the RPS will not change. The vibrational sensor is either an accelerometer attached to the nozzle shell or a pressure transducer in contact with the fluid within the nozzle. The frequency range over which the power spectrum is plotted is chosen empirically so that the vibrational resonances that characterize the power spectrum are dominated by energy produced by nozzle flow.

2. Subsequent current power spectra (Current Power Spectrum or CPS) are taken in either real time by a hard wired system monitored by a computer or taken periodically by operating personnel at the specific nozzle.

3. Comparison of the RPS with the CPS is made either by suitable computer pattern recognition algorithms or visually by personnel and changes noted.

4. Changes in the operating conditions of a specific nozzle are then made to restore the CPS to the RPS.

5. The time variation of the vibratory signal that accompanies the taking of both the RPS and the CPS can be noted and used either by a suitable computer algorithm or by observation of personnel to supply complementary information on the time variation of the state of fluid flow within the nozzle within the measurement time.

The invention will be better understood from the following description given by way of example and with reference to the accompanying drawings, wherein:-

Figure 1 shows a schematic diagram of one form of nozzle performance monitoring system according to the present invention.

Figure 2 shows a schematic figure of two nozzles being fed oil and steam through common headers.

Figure 3 shows the relationship between signal measured from the accelerometer and the power spectrum.

Figure 4 shows the variation of the power spectrum as the flow conditions of a nozzle vary. The ordinate is in (volts)^2 Hz. The abscissa is in Hz. All pressures, P, are in PSI (1 PSI = 6894,76 Pa).

Figure 5 is another example of the variation of the power spectrum as the flow conditions of the nozzle vary. The ordinate is in (volts)^2 /Hz. The abscissa is in Hz. All pressures, P, are in PSI (1 PSI = 6894,76 Pa).

Figure 6 shows the spectra of a nozzle obtained with a pressure transducer for a variety of flow conditions. The ordinate is the log of RMS pressure. The abscissa is in Hz from 0 to 32000 Hz.

Figure 7 shows the time variation of the vibrating signal and the corresponding power spectrum for the same nozzle conditions.

Figure 8 shows the time variation of the vibrating signal for normal oil flow and unstable oil flow.

Disclosed hereinbelow is a method for non-intrusively determining if the liquid-gas mixture exiting a nozzle has departed from desired operating conditions. If it has, then the operating conditions of the nozzle are changed to return to the desired flow conditions, or the nozzle is cleaned, or removed from service. The method will be illustrated and described by a heavy feed fluid bed thermal conversion process such as in a fluid bed coker where the nozzle contains feed oil and steam. However, it is not limited to petrochemical applica-

tions but to any situation where nozzle performance is to be monitored, and in particular where it is difficult to directly monitor flow through a specific nozzle and where the fluid being carried, or the nozzle environment, leads to a high probability of unreliable nozzle performance.

Figure 1 shows a schematic diagram of a representative coker feed nozzle 4 inserted through a coker wall 7. Fluid bed cokers can contain anywhere from twenty to sixty such nozzles injecting feed at the rate of approximately ten to fifty gallons (1 gallon = 3,78 liter) a minute. In one embodiment of the invention, an accelerometer 5 is placed in close proximity to the nozzle 4. In Figure 1, the accelerometer 5 is placed on the rodding plug 6, but any location in proximity to the nozzle and where the accelerometer is sensitive to changes in flow conditions is acceptable.

As shown in Figure 2, for a given reactor, several nozzles 4 and 11 may be interconnected so that steam and oil are supplied through a steam header 14 and oil header 16 to all nozzles simultaneously. In this case, the performance of one nozzle (upstream) can affect the power spectra observed for another (discussed below).

The electrical signal for the accelerometer is proportional to the nozzles vibration intensity and a plot of the mean square acceleration per unit frequency range or simple mathematical operations on this quantity (e.g. taking the square root of this quantity and multiplying by a constant to form a plot of the root mean square acceleration or taking the logarithm of the quantity to form a "db" plot) is an appropriate power spectrum for the purpose of the present disclosure. In one use the sensor signal is amplified and transmitted by an appropriate data link to a control room as shown in Figure 1. In the control room, the signal is processed by a spectrum analyzer or fast fourier transform signal processor. Also in the control room by an appropriate algorithm, the RPS is displayed and stored in memory. Similarly current power spectra or CPS are taken in real time and by a suitable pattern recognition algorithm compared to the RPS. Changes between the CPS and the RPS are brought to the attention of the operator to indicate changes in the flow regime of a specific nozzle for subsequent correction.

To assist the operator in interpreting the changes in the CPS from the RPS, a "dictionary" of characteristic CPS associated with specific flow conditions can be contained in memory and displayed to indicate the direction of changes to be made. Again the "dictionary" is feed nozzle specific and has been generated empirically due to the well known complexity of two phase flow in complex piping. The determination of a dictionary is illustrated and described below.

In addition an analysis of the time variation of the real time signal from the accelerometer sensor (time signature) is used to detect the presence of unstable flow during the measurement time.

Alternatively, the vibratory signal from the accelerometer can be processed at the nozzle by a portable spectrum analyzer operated by a technician and changes in the CPS from the RPS noted and corrective action taken with respect to a nozzle can be taken immediately at the nozzle location.

In another embodiment, the accelerometer 5 is replaced by a dynamic pressure transducer 8 in contact with the fluid. In this case, the transducer penetrates the rodding plug to contact the fluid. Alternately, the transducer 8 may be located elsewhere along the nozzle (see Fig. 1). The frequency dependent pressure can be used to generate a power spectrum to serve as an RPS or a CPS.

Figure 3 exhibits the relationship between the time varying electrical signal produced either by an accelerometer in contact with the mechanical shell of a feed nozzle or a pressure transducer in contact with the two phase mixture within the nozzle and the frequency distribution of the vibrational energy generated by the nozzle in its operation. It also shows the square of that signal as a function of time and frequency and exhibits the well known relationship between the area under the power spectrum and the mean square signal (mean square acceleration or mean square pressure fluctuation when the transducers are correctly calibrated) produced by the vibrational sensor.

Determining Of Dictionary For a Nozzle

A dictionary for a given nozzle is obtained by doing a power spectrum analysis for different flow conditions. Figure 4 shows a sequence of power spectra of a nozzle for changes in flow conditions as induced by oil flow changes by valve (1) in Fig. 1 or steam flow changes by valve 2 in Fig. 1, or conditions of nozzles upstream on the same oil and steam headers.

Figure 4(a) shows a power spectrum for a nozzle where the oil and steam are set at normal pressure of 175 but which exhibits unstable and undesirable flow. The pressure is measured at point 10 in Figure 1. The nozzle is then rodded and cleaned. Figures 4(b), 4(c), 4(d) and 4(e) show a power spectra of the nozzle as oil flow is reduced with some steam input until the oil flow is shut off. The pressures, P, are 150, 130, 100 and 20, respectively. There is no chugging. Figure 4 (f) shows the power spectrum for the nozzle after normal oil and steam flow are resumed. Pressure is 175 and there is no chugging. Figure 4(g) shows the power spectrum for the nozzle with the steam shut off and only oil flow. Pressure is 300. Figure

4(h) shows the power spectrum of the nozzle after normal oil and steam flow are resumed. The pressure is 175 and there is no chugging.

Nozzle malfunctions resulting from an inadequate mixing of feed and steam may be correlated to the various open and closed valves as presented and discussed in Figure 4. These include: partial or complete blockage of the nozzle due to deposits, oil off, steam off, improper proportions of steam to oil, fluctuating flow or chugging, as well as poor atomization, time dependent shifts in flow between two nozzles on the same feed ring as well as physically damaged nozzles. Figures 5 is another example of power spectra generated by an accelerometer in contact with the shell of the nozzle corresponding to such states. Figure 5 shows acceleration power spectra taken for a different feed nozzle under different flow conditions. Pressure is measured at point 10 in Figure 1.

Figure 5(a) shows the power spectrum for the nozzle while it is plugged (no flow). Figure 5(b) shows the power spectrum of the nozzle when it is chugging showing unstable flow. The pressure is 183. Figure 5(c) shows the power spectrum of the nozzle after is has been cleared showing stable flow. The pressure is again 183. Figure 5(d) shows the power spectrum of the nozzle with only oil flow (steam off). Pressure is 300. Figure 5(e) shows the power spectrum of the nozzle with only steam flow (oil off). Pressure is 50. Figure 5(f) shows the power spectrum of the nozzle when another nozzle upstream on the same oil and steam headers is plugged. In this case, pressure is measured at point 12 in Figure 1. It is important to note that despite differences between the power spectra of Figure 4 and 5, each is a "fingerprint" of flow states.

An accelerometer will often be the vibrational transducer of choice for generation of the RPS and CPS. However a pressure transducer is an alternative that exhibits some advantages. It is often possible to place the pressure transducer at a location where it can not be inadvertently damaged when cleaning a nozzle. There is no difference in the frequency coverage between an accelerometer and a pressure transducer for the vibratory signals of interest to passive acoustic feed nozzle monitoring. Furthermore, the efficiency of a pressure transducer in contact with the fluid is little affected by a build up of coke or other solids on its active surface since it is acoustic rather that mechanical contact that is important.

As discussed above, a dynamic pressure transducer (8) in contact with the fluid within the feed nozzle at a fixed location on the feed nozzle may be used to obtain a power spectrum. The power spectrum from such a transducer is shown in Fig. 6(a) through 6(f) show the power spectra of a

nozzle when it is operating correctly (6a), steam only (6b), same steam, reduced oil (6c), oil, no steam (6d) induced slugging by adding steam (6e) and nozzle instability induced by plugging upstream nozzle (6f). A log scale is used for these figures to give greater dynamic range.

From the above figures, it is clear that the pressure transducer produces an equally distinct power spectrum to function as a CPS or RPS as does the accelerometer generated power spectrum. However the pressure transducer generated power spectrum is simpler in that it contains a smaller number of peaks and hence more changes in it are more readily recognized by either a human observer in the case of periodic nozzle monitoring or by simpler computer pattern recognition algorithm in the case of continuous or real time nozzle monitoring.

The simplicity of the pressure transducer generated power spectrum can be understood if we note that the peaks in the power spectrum arise from resonances in the fluid contained in the bore or ancillary tubing of the feed nozzle which have been excited by broadband noise from the fluid exiting the nozzle tip. The peaks in the power spectrum generated by the accelerometer in contact with the nozzle shell contain as well vibrational resonances associated with the mechanical vibrational modes of the nozzle as well as structural modes of the process vessel. Using the concept of acoustic impedance, it is easily shown that the signals produced by resonances in the fluid are favored over other resonances when measured in the fluid by a factor of almost 100. Apart from this fact, another advantage for the pressure transducer generated CPS is that it may often be advantageous to use a pressure transducer for convenience of location and protection from unintended damage during nozzle maintenance.

As discussed above, the time variation of the vibrational signal also may be used to obtain information regarding the state of the flow of fluid in the nozzle. Figure 7(b) shows the time variation of the vibrating signal and the corresponding Fourier transform in Figure 7(a), the power spectrum as a function of frequency for a chugging nozzle. It is sometimes more convenient to use the time variation of the probe signal to detect unstable flow. Fig. 8 compares the time variation for stable oil flow (a) and unstable oil flow, chugging (b).

Claims

1. An acoustic nozzle monitoring process for correcting the operating conditions of a feed nozzle (4) injecting a liquid/gas mixture into a process vessel or chamber so as to maintain the correct mixing of said liquid and gas ex-

iting the nozzle, comprising:

(a) determining a Reference Power Spectrum (RPS) from a vibrational sensor acoustically coupled to the fluid in said nozzle when said nozzle (4) is performing at a standard mixing or flow condition which is the desired operating state of the nozzle and where the vibrational resonances that characterize the RPS are dominated by the energy associated with the flow through the nozzle in the frequency range over which the Power Spectrum is determined;

(b) determining a Current Power Spectrum (CPS) at a later time from said vibrational sensor when said nozzle is performing at an unknown mixing or flow condition;

(c) comparing the signature of said CPS with the signature of said RPS;

(d) correcting the flow state of the nozzle by changing the variables controlling the relative volumes of gas and liquid entering the nozzle, when the comparison indicates a departure of said unknown condition from said standard condition; and

(e) verifying the return to the desired flow state by recognising when the signature of the CPS substantially exhibits the signature of the RPS.

2. A process as claimed in claim 1, wherein said vibrational sensor is an accelerometer (5).

3. A process as claimed in claim 1, wherein said vibrational sensor is a dynamic pressure transducer (8) in contact with the fluid mixture in the nozzle.

Patentansprüche

1. Akustisches Düsenüberwachsungsverfahren zur Korrektur der Betriebsbedingungen einer Zufuhrdüse (4), die eine Flüssigkeit/Gas-Mischung in ein Verfahrensgefäß oder eine Verfahrenskammer einspritzt, um so die korrekte Mischung der Flüssigkeit und des Gases, die die Düse verlassen, aufrechtzuerhalten, bei dem

(a) ein Referenzleistungsspektrum (RPS) eines Vibrationssensors bestimmt wird, der mit dem Fluid in der Düse akustisch gekoppelt ist, wenn die Düse (4) bei einer Standard-Mischungs- oder -Fließbedingung arbeitet, die der gewünschte Betriebszustand der Düse ist, und bei der die Vibrationsschwingungen, die das RPS kennzeichnen, von der Energie dominiert sind, die mit dem Fließen durch die Düse in dem Frequenzbereich verbunden ist, über den das

Leistungsspektrum bestimmt wird,

(b) zu einer späteren Zeit ein Stromleistungsspektrum (CPS) des Vibrationssensors bestimmt wird, wenn die Düse unter einer unbekannten Mischungs- oder Fließbedingung arbeitet,

(c) die Signatur des CPS mit der Signatur des RPS verglichen wird,

(d) der Fließzustand der Düse durch Veränderung der Variablen, die die relativen Volumen von Gas und Flüssigkeit kontrollieren, die in die Düse eintreten, korrigiert wird, wenn der Vergleich eine Abweichung der unbekannten Bedingung von der Standardbedingung anzeigt, und

(e) die Rückkehr zu dem gewünschten Fließzustand verifiziert wird, indem erkannt wird, wenn die Signatur des CPS im wesentlichen die Signatur des RPS zeigt.

2. Verfahren nach Anspruch 1, bei dem der Vibrationssensor ein Beschleunigungsmesser (5) ist.

3. Verfahren nach Anspruch 1, bei dem der Vibrationssensor ein dynamischer Druckumwandler (8) ist, der mit der Fluidmischung in der Düse in Kontakt steht.

Revendications

1. Procédé acoustique de contrôle de buse destiné à corriger les conditions de fonctionnement d'une buse d'alimentation (4) injectant un mélange liquide/gaz dans une cuve ou une chambre de traitement de façon à maintenir le mélange correct dudit gaz et dudit liquide sortant de la buse, comportant :

(a) la détermination d'un spectre d'énergie de référence (RPS) provenant d'un capteur de vibration couplé de manière acoustique au fluide dans ladite buse lorsque ladite buse (4) fonctionne dans une condition d'écoulement ou de mélange standard qui est l'état de fonctionnement souhaité de la buse et où les résonances de vibration qui caractérisent le spectre d'énergie de référence sont dominées par l'énergie associée à l'écoulement à travers la buse dans la plage de fréquence pour laquelle le spectre d'énergie est déterminé;

(b) la détermination d'un spectre d'énergie courant (CPS) un instant plus tard à l'aide dudit capteur de vibration lorsque ladite buse fonctionne dans une condition d'écoulement ou de mélange inconnue;

(c) la comparaison de la signature dudit spectre d'énergie courant avec la signature

dudit spectre d'énergie de référence;

(d) la correction de l'état d'écoulement de la buse en modifiant les variables commandant les volumes relatifs de gaz et de liquide entrant dans la buse, lorsque la comparaison indique un écart de ladite condition inconnue par rapport à ladite condition standard; et

(e) la vérification du retour à l'état d'écoulement souhaité en reconnaissant que la signature du spectre d'énergie courant présente sensiblement la signature du spectre d'énergie de référence.

2. Procédé selon la revendication 1, dans lequel ledit capteur de vibration est un accéléromètre (5).

3. Procédé selon la revendication 1, dans lequel ledit capteur de vibration est un transducteur de pression dynamique (8) en contact avec le mélange de fluide dans la buse.
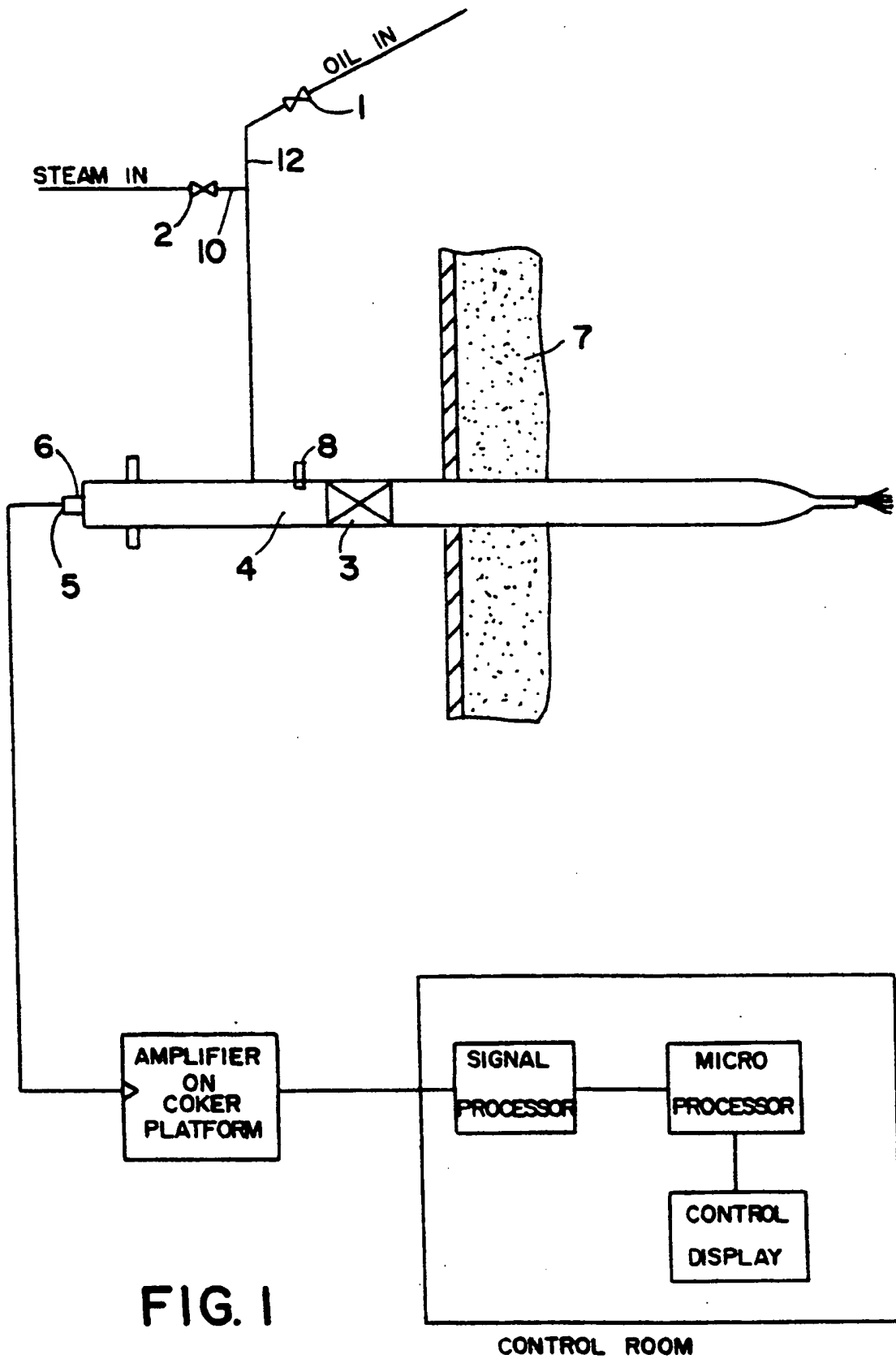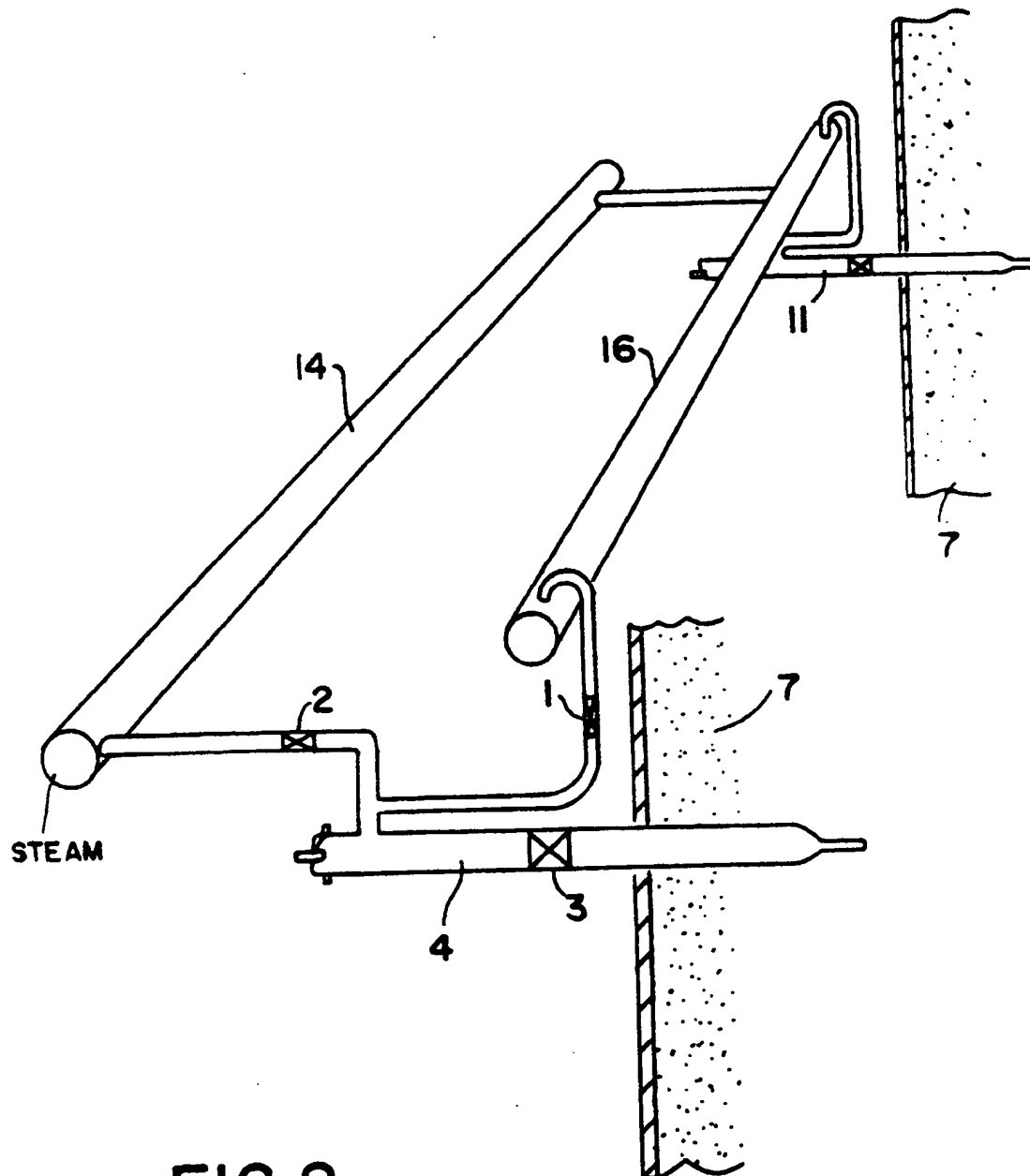
FIG. I

FIG. 2

POWER SPECTRUM EXHIBITS FREQUENCY DEPENDENCE OF RANDOM TIME SIGNAL
FROM ACCELEROMETER (PRESSURE)

$A(T)$

T = TIME

MEAN ACCELERATION (PRESSURE)

$\langle A(T) \rangle = 0$

$A^2(T)$

$\langle A^2(T) \rangle$

MEAN SQUARE ACCELERATION
(PRESSURE)

$\langle A^2(T) \rangle = 2 \int S(F) \, dF$

POWER SPECTRUM S(F)

FREQUENCY F (Hz)

$S = POWER\ SPECTRUM = \dfrac{POWER}{Hz}$
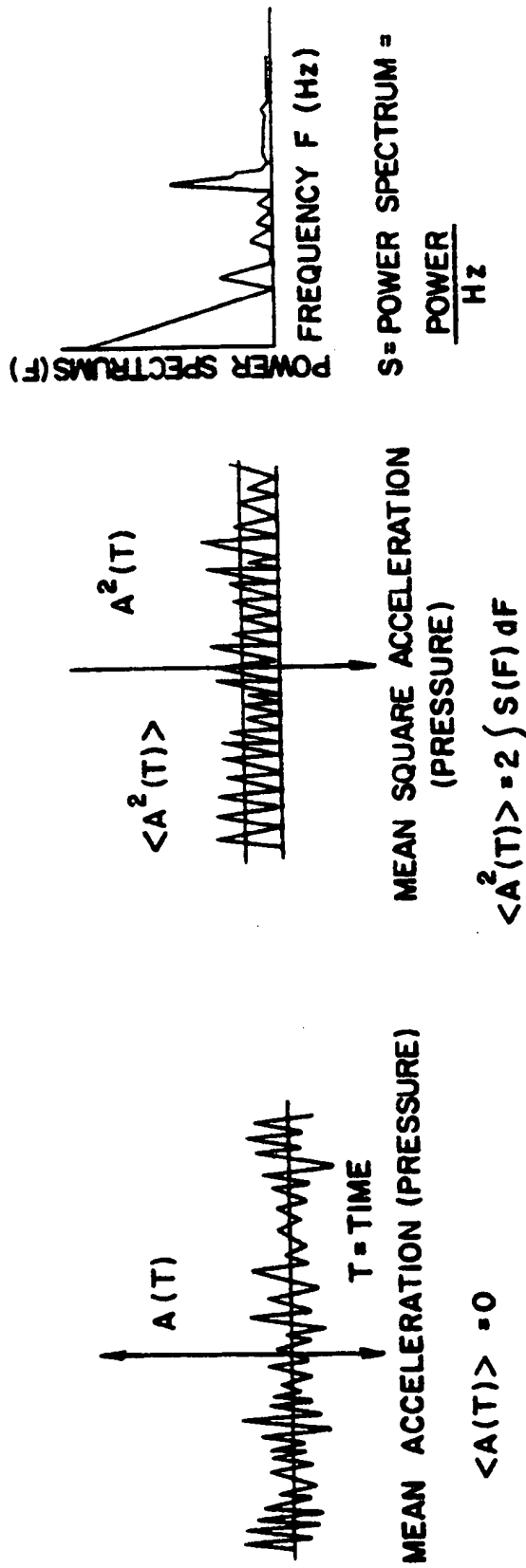
FIG. 3
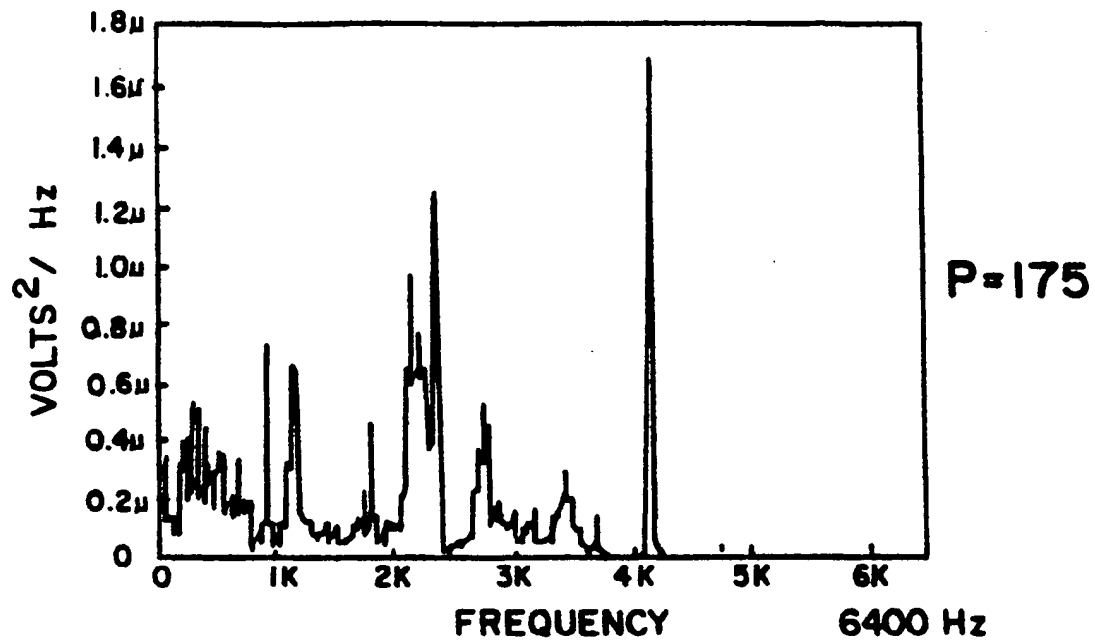
FIG.4a

FIG.4b

FIG.4c

FIG.4d

FIG.4e

P=20

FIG.4f

P=175

FIG.4g

FIG.4h

FIG.5a

FIG.5b

FIG.5c

FIG.5d

FIG. 5 e

FIG. 5 f

FIG. 6 a

LOG RMS PRESSURE

FREQUENCY, F   3200 Hz

FIG. 6 b

LOG RMS PRESSURE

FREQUENCY, F   3200 Hz

FIG. 6 c

LOG RMS PRESSURE

FREQUENCY, F   3200 Hz

FIG. 6 d

FIG. 6 e

FIG. 6 f

FIG.7a

V²/Hz

712 Hz · FREQUENCY, F · 3.2k Hz

FIG.7b

mv

0 · 400 ms · TIME,t · 900ms

FIG.8a

0 · 0.5 sec. · 1.0

mv

TIME, t

FIG.8b

mv

400 ms · 900ms

TIME, t